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Ali

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(54) **SYSTEM AND METHOD FOR MOBILE LOCATION DETECTION IN SYNCHRONOUS WIRELESS SYSTEMS**

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(21) Appl. No.: **09/372,153**

(22) Filed: **Aug. 20, 1999**

Related U.S. Application Data

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(51) **Int. Cl.**^{7} **H04Q 7/20**; G01S 3/02

(52) **U.S. Cl.** **455/456**; 342/450; 342/463; 342/464; 455/404

(58) **Field of Search** 455/456; 342/450, 342/463, 464, 457, 387; 340/988

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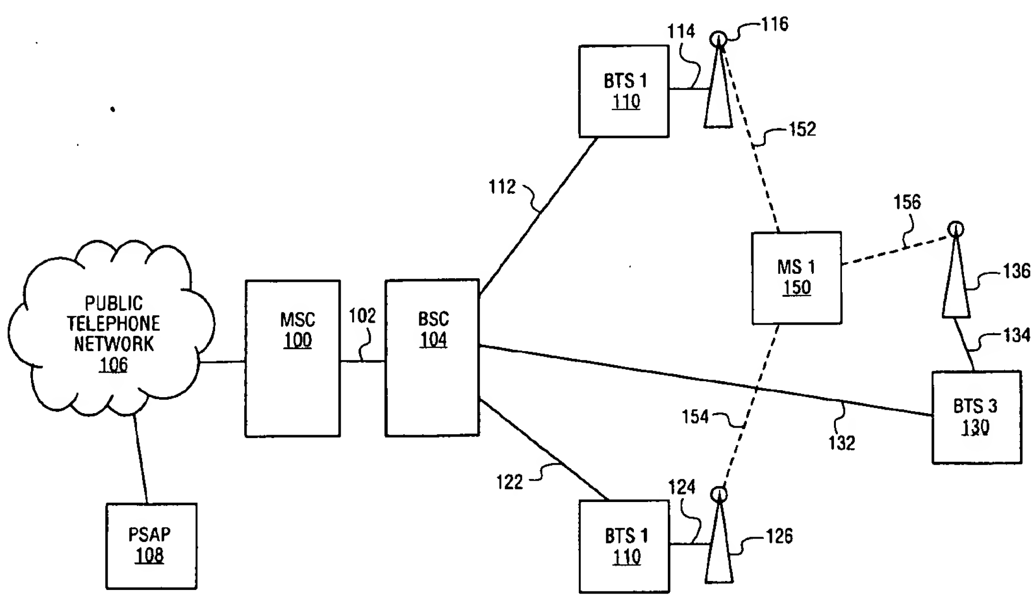
(57) **ABSTRACT**

A system and method for determining the geographic location of a mobile station in a mobile telephone system is disclosed. The system broadcasts a series of forward link triangulation signals from an array of base transceiver stations, so that a mobile station may determine the differential times of arrival, and thereby the mobile station's location.

23 Claims, 6 Drawing Sheets



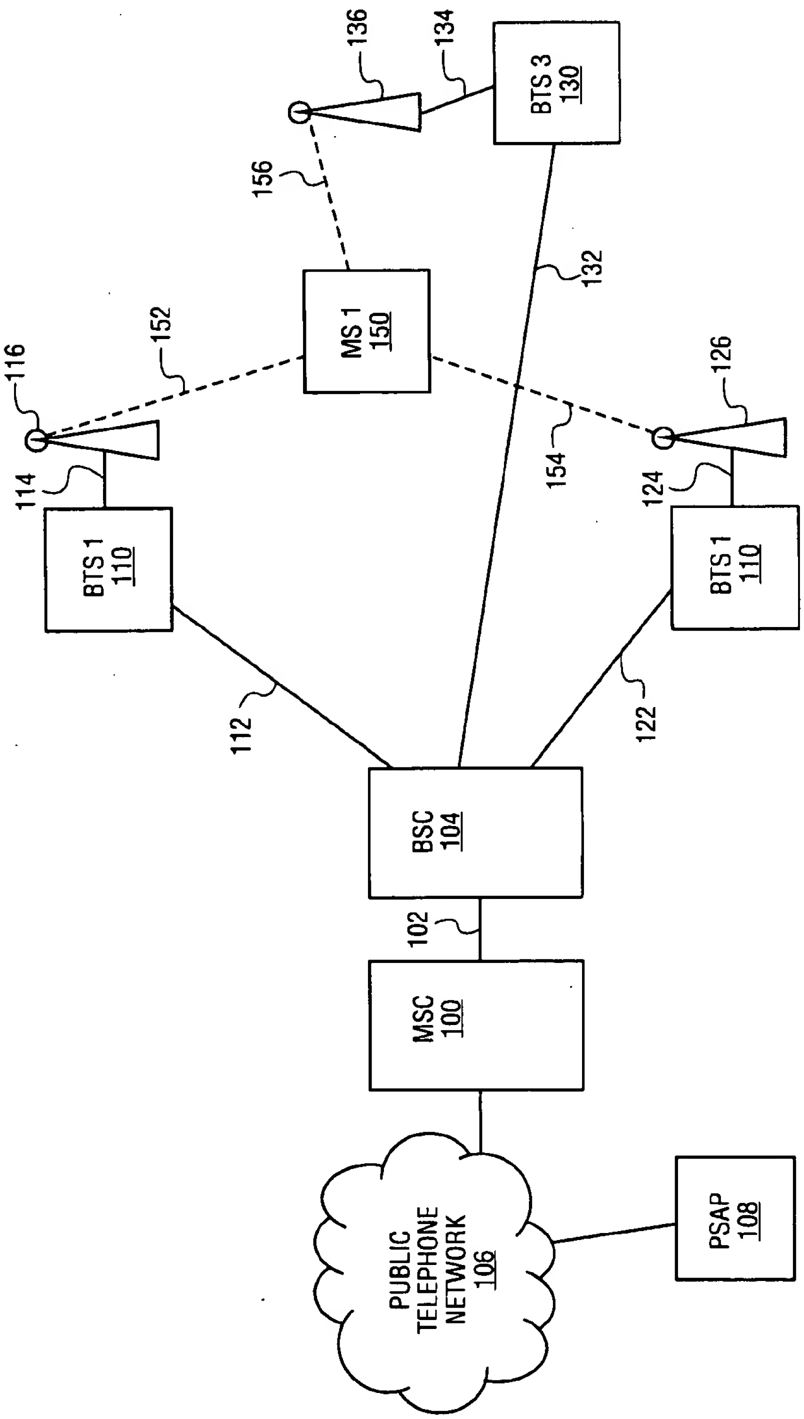

BTS 3
130
136
134
156
MS 1
150
132
116
152
126
154
114
124
BTS 1
110
BTS 1
110
112
122
BSC
104
102
MSC
100
PUBLIC
TELEPHONE
NETWORK
106
PSAP
108

FIG. 1

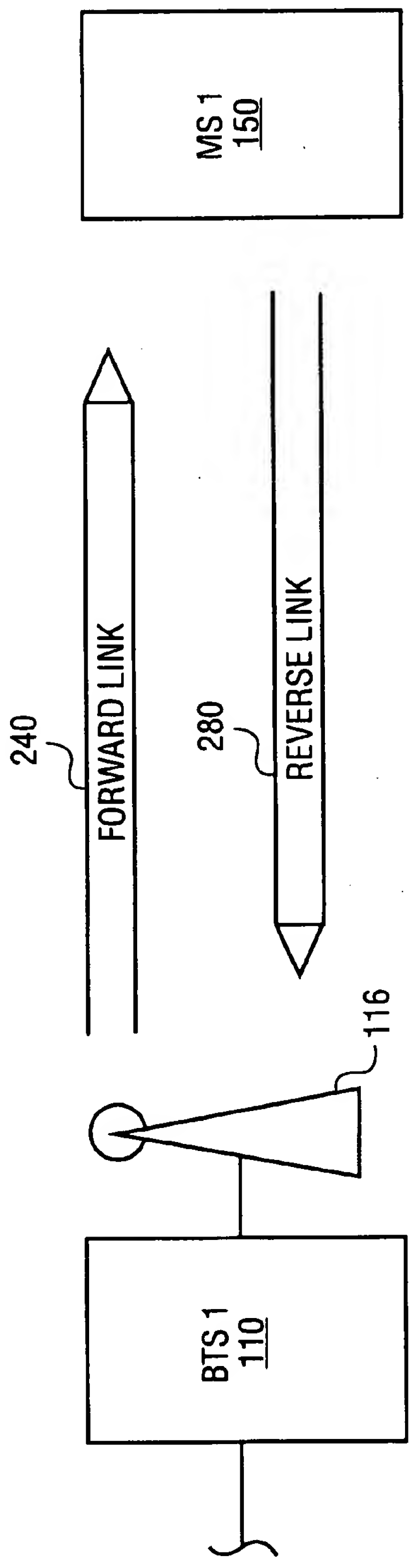


FIG. 2

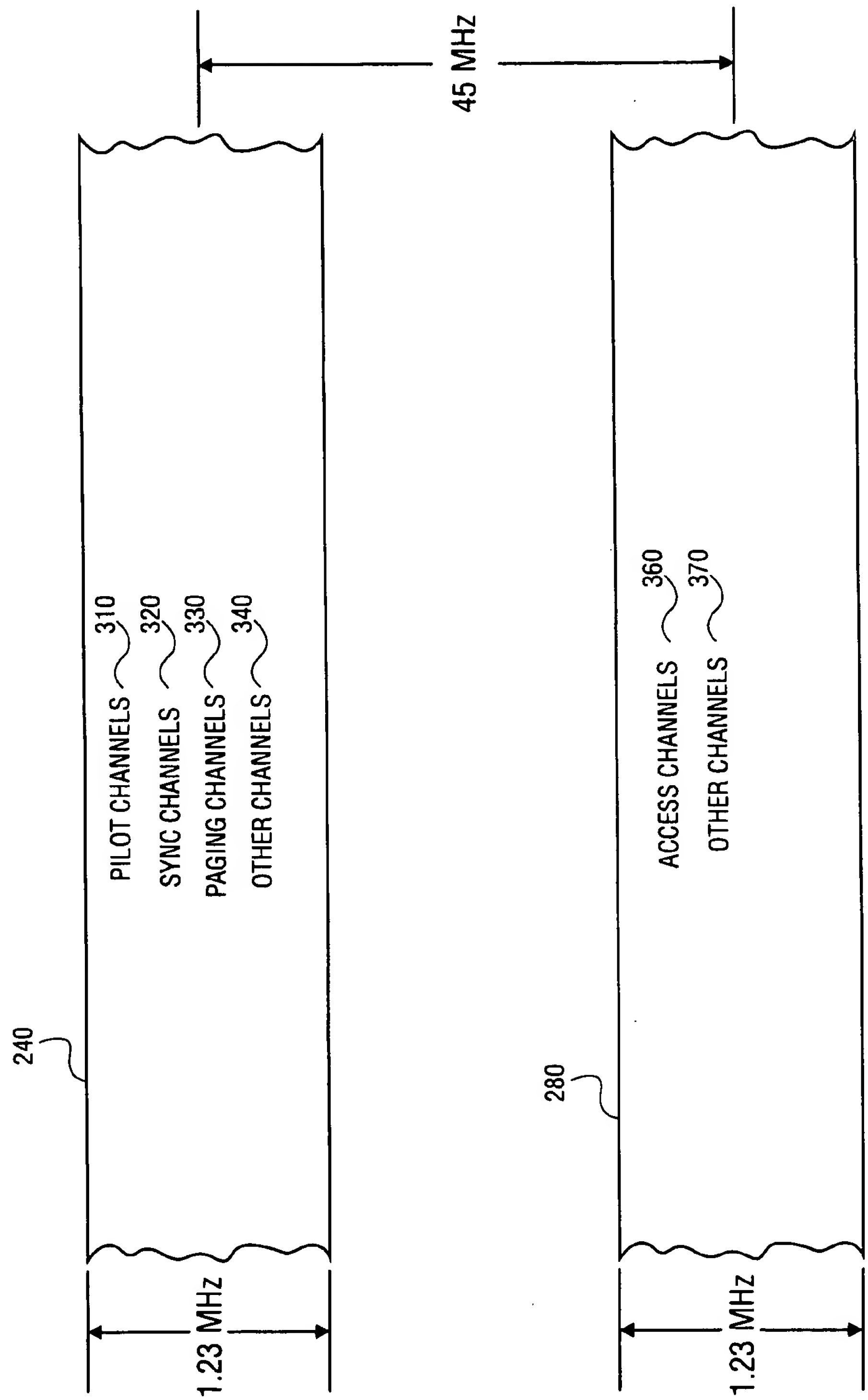

45 MHz
PILOT CHANNELS 310
SYNC CHANNELS 320
PAGING CHANNELS 330
OTHER CHANNELS 340
240
ACCESS CHANNELS 360
OTHER CHANNELS 370
280
1.23 MHz
1.23 MHz

FIG. 3

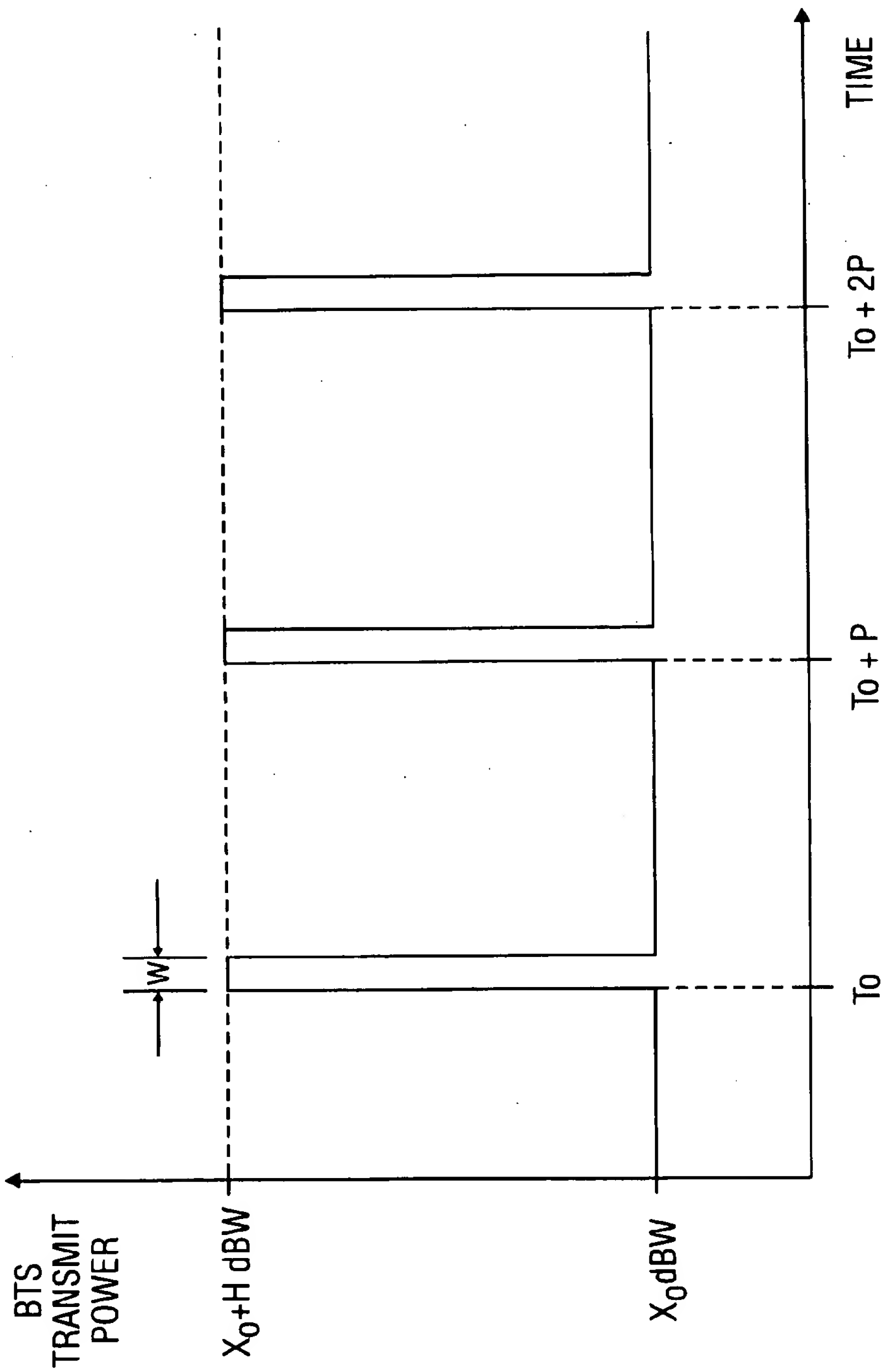


FIG. 4

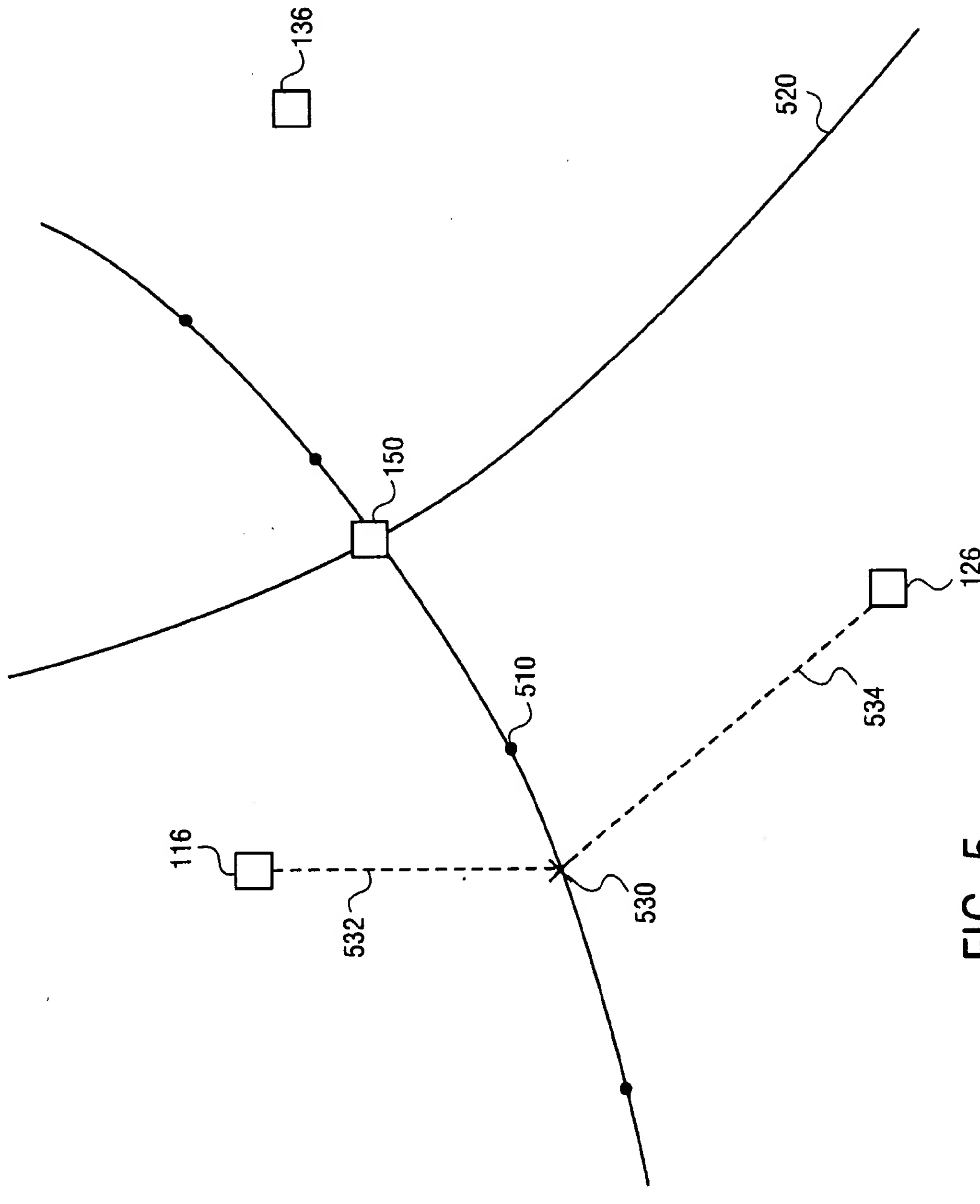


FIG. 5

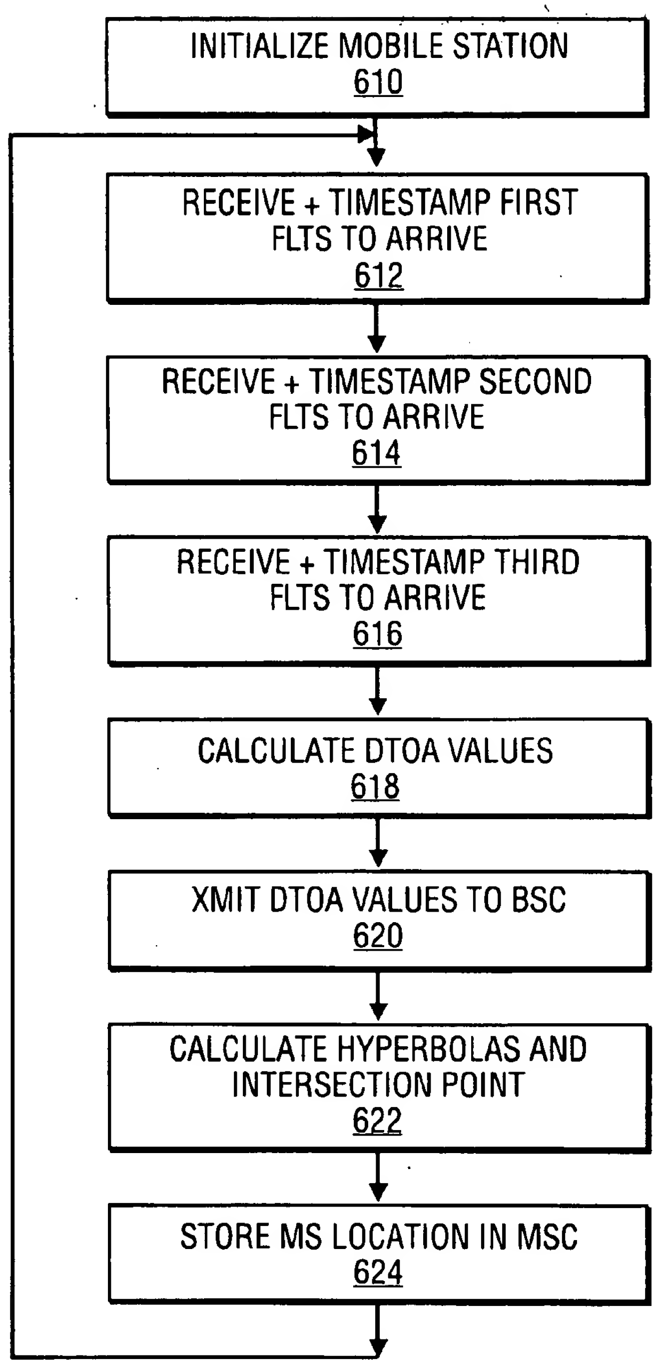

INITIALIZE MOBILE STATION
610
RECEIVE + TIMESTAMP FIRST FLTS TO ARRIVE
612
RECEIVE + TIMESTAMP SECOND FLTS TO ARRIVE
614
RECEIVE + TIMESTAMP THIRD FLTS TO ARRIVE
616
CALCULATE DTOA VALUES
618
XMIT DTOA VALUES TO BSC
620
CALCULATE HYPERBOLAS AND INTERSECTION POINT
622
STORE MS LOCATION IN MSC
624

FIG. 6

SYSTEM AND METHOD FOR MOBILE LOCATION DETECTION IN SYNCHRONOUS WIRELESS SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of the filing date of U.S. provisional patent application, entitled "Mobile Location Detection Method in Synchronous Wireless Systems", Ser. No. 60/097,248, filed Aug. 20, 1998.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

The present invention relates to the field of mobile telephony. In particular, the present invention relates to an apparatus and a method for determining the geographic location of a mobile transceiver.

(2) Description of Related Art

Emergency calls placed from someone involved in or observing an emergency situation, are easily placed and routed to the appropriate emergency response authorities by dialing the number 911. This system is therefore called the 911 call response system. Because the person placing the call may be under stress, duress, or be otherwise incapacitated, a newer version of the 911 call response system, called Enhanced 911 (E911), is entering service. In the E911 system the location of the caller is sent to the emergency response authorities, enabling a response even when the caller can do little more than dial the number 911. For calls placed from a fixed location, the telephone companies' billing databases may be searched to give a location associated with each originating telephone number.

The E911 system is more difficult to implement for mobile (cellular) telephones. Cellular telephones by their nature may vary in location. However, at the present time about half of all E911 calls are placed from a cellular phone. For this reason the Federal Communications Commission (FCC) has mandated that a high percentage of cellular E911 calls be able to report the caller's location within 125 meters.

One method of locating the mobile telephone's location consists of placing additional equipment into the mobile telephone so that it may independently determine its geographic location. For example, a Global Positioning System (GPS) receiver could be incorporated into the mobile telephone. This method has several drawbacks. The addition of the GPS receiver adds cost and bulk to the mobile receiver. Additionally, the GPS receiver requires clear radio-frequency (RF) access to multiple GPS satellites in order to calculate a position. There are many circumstances where a mobile phone could place a call yet not have RF access to multiple GPS satellites.

Another method of locating the mobile telephone's location derives the location using only the mobile telephone system's equipment. One method proposed to allow the temporary location of a cellular telephone to be determined and routed to the emergency response authorities is called reverse link triangulation. Cellular phone connections consist of forward links sent from fixed base stations to a mobile station, and reverse links sent from a mobile station to a fixed base station. In reverse link triangulation, a mobile station broadcasts a special signal that may be received by multiple base stations. If the base stations each have a synchronized local time standard, the differential time of arrival (DTOA) of the special signal at the various base stations may be determined by reading each local time standard when the special signal arrives at each base station. From the DTOA data and the speed of light may be calculated the distance from the mobile station to each base station. If three or more base stations receive the special signal, and the location of these base stations is known, then a computational element in the cellular phone system may determine the location of the mobile station.

Reverse link triangulation advantageously utilizes the existing mobile telephone system. However, it has limitations. The mobile telephone is limited in transmission power. For this reason it is not always possible for the special signal of reverse link triangulation to be received by three or more base stations.

Therefore a method for reliably determining the geographic location of a mobile telephone is at issue in mobile telephone systems.

SUMMARY

A system and method for determining the geographic location of a mobile station in a mobile telephone system is disclosed. The method begins with broadcasting a series of forward link triangulation signals from a series of base transceiver stations. The mobile station then receives and timestamps the forward link triangulation signals. By calculating a first hyperbola and a second hyperbola from these timestamped forward link triangulation signals, the intersection of the first hyperbola and second hyperbola will yield the desired geographic location of the mobile station.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, aspects, and advantages of the present invention will become more fully apparent from the following detailed description, appended claims, and accompanying drawings in which:

FIG. 1 is a block diagram of a mobile (cellular) telephone system, according to one embodiment of the present invention;

FIG. 2 is a block diagram of forward and reverse links, according to the FIG. 1 embodiment;

FIG. 3 illustrates the channel allocation in the links of FIG. 2, according to one embodiment of the present invention;

FIG. 4 illustrates a transmit power timing diagram for the forward link of FIG. 2, according to one embodiment of the present invention;

FIG. 5 illustrates the geographical hyperbolas of constant differential time of arrival, according to one embodiment of the present invention; and

FIG. 6 illustrates a flowchart of the determination of the mobile station's geographic location, according to an embodiment of the present invention.

DETAILED DESCRIPTION

In the following description, numerous specific details are set forth to provide a thorough understanding of the present invention. However, one having an ordinary skill in the art may be able to practice the invention without these specific details. In some instances, well-known circuits, structures, and techniques have not been shown in detail to not unnecessarily obscure the present invention.

Referring now to FIG. 1, a block diagram of a mobile (cellular) telephone system is illustrated, according to one embodiment of the present invention. In different embodiments several different kinds of synchronous wireless

mobile telephone systems are envisioned. For the purpose of illustration, the Code Division Multiple Access (CDMA) mobile telephone system is shown. A common form of CDMA system is one designed in accordance with Telecommunications Industry Association (TIA) specification TIA/IS-95A (May 1995), which herein is incorporated by reference.

In the FIG. 1 embodiment, major components of the CDMA mobile telephone system are the mobile switching center (MSC) **100**, the base station controller (BSC) **104**, several base transceiver stations (BTS) **110**, **120**, **130**, with associated antennas **116**, **126**, **136**, and at least one mobile station (MS) **150**.

The MSC **100** comprises the gateway between a regional mobile telephone system and the overall public telephone network **106**. The E911 calls originating within the regional mobile telephone system are routed to the public safety access point (PSAP) **108** through the public telephone network **106** by MSC **100**. Associated with the MSC **100** may be several databases used in controlling the mobile telephone system, such as a home location register and a visitor location register.

The BSC **104** includes a control computer for controlling the interaction of the BTSs. The BSC **104** may control the transmit power levels in the BTSs, and may also cause the transmission of messages which will control the transmit power levels of an MS **150**. One of the prime functions of the BSC **104** is to multiplex and de-multiplex the various control signals and voice/data channels in the mobile telephone system.

Each BTS **110**, **120**, **130** contains several transmitters and receivers, one for each frequency band. Each BTS **110**, **120**, **130** is connected via a land-line **112**, **122**, **132**, respectively, to the BSC **104**. Each BTS **110**, **120**, **130** is attached to an antenna **116**, **126**, **136**, respectively, via cabling. Typically each BTS **110**, **120**, **130** is located a very short distance away from corresponding antenna **116**, **126**, **136**.

Because the CDMA mobile telephone system utilizes packets of data and pseudo-random (PN) codes, each transmission of the several BTSs must be synchronized to a common time standard. In the present embodiment the Global Positioning System (GPS) is used to distribute a synchronized time standard. Therefore each BTS **110**, **120**, **130** contain GPS receiver circuits sufficient to maintain a common time standard.

Referring now to FIG. **2**, a block diagram of forward and reverse links is illustrated, according to the FIG. **1** embodiment. An ongoing call in the CDMA mobile telephone system includes a wide bandwidth radio-frequency (RF) communications channel transmitted by the BTS **1 110** through antenna **116** and received by MS **1 150**, called a forward link **240**. The ongoing call also includes a wide bandwidth RF communications channel transmitted by the MS 1 150 through its attached antenna (not shown) and received by BTS **1 110**, called a reverse link **280**. Both the forward link **240** and the reverse link **280** may carry multiple calls which may be separated by a series of unique code sequences, each associated with one of the mobile stations.

MS **1 150** begins an initialization process in order to access the CDMA mobile telephone system. MS **1 150** first determines a suitable carrier channel by scanning for the signal strength of incoming radio carrier channels. The MS **1 150** then determines the strongest radio carrier channel that contains a control channel. Once this control channel is found, MS **1 150** receives control information including, among other things, the data required for MS **1 150** to access the channel and the maximum transmit power MS **1 150** should use when initiating a call. In the FIG. **2** embodiment, BTS **1 110** will transmit a control channel on forward link **140**.

Once the control information has been received, MS **1 150** transmits an identifying message on reverse link **280** to identify MS **1 150** to the CDMA mobile telephone system.

Referring now to FIG. **3**, the channel allocation in the links of FIG. **2** is shown, according to one embodiment of the present invention. Many separate channels are carried simultaneously within a forward link **240** and a reverse link **280**. In one embodiment, forward link **240** and reverse link **280** each have 1.23 MHz bandwidth, and the center frequency of each link are separated by 45 MHz. The channels are embedded within the forward link **240** and the reverse link **280** by the CDMA modulator/demodulators. The forward link **240** uses quadrature phase shift keying (QPSK) and the reverse link **280** uses offset quadrature phase shift keying (O-QPSK). Each channel is identified by a unique code.

Within forward link **240**, pilot channels **310** contain beacon, timing and phase reference, and signal strength for power control for the MS **1 150**. The pilot channels **310** usually are the strongest RF powered signals sent from BTS **1 110**. The pilot channels contain a PN code that is time shifted for identifying which BTS is transmitting.

Sync channels **320** provide MS **1 150** with time synchronization information.

Paging channels **340** are used to communicate with MS **1 150** when no call is in progress. The paging channels **340** may contain system and access parameters necessary for the MS **1 150** to initiate calls. Paging channels **340** may additionally contain signals indicating an incoming call is pending so that MS **1 150** may initiate the reception of an incoming call.

Other channels **340** within forward link **240** may include forward traffic channels. The forward traffic channels are the primary channels used after a call is initiated to carry voice and data from BTS **1 110** to MS **1 150**.

Within reverse link **280**, access channels **360** carry responses generated by MS **1 150** to commands and call origination requests sent by BTS **1 110**. The access channels **360** may additionally carry other signals generated by MS **1 150** when no reverse traffic channel is established.

Other channels **370** within reverse link **280** may include reverse traffic channels. The reverse traffic channels are the primary channels used after a call is initiated to carry voice and data from MS **1 150** to BTS **1 110**.

In one embodiment of the present invention, a special signal is used within forward link **240** for the purpose of determining the geographical location of MS **1 150**. This signal, called the forward link triangulation signal (FLTS), is transmitted by each BTS at the exact same time, using the common time standard maintained in each BTS and synchronized by GPS. The FLTS may be carried by the pilot channels **310** or it may be carried by the sync channels **320**. In other embodiments the FLTS may be carried by other circuits **340** of the forward link **240**.

The FLTS may be sent periodically or continuously. In either case, MS **1 150** may receive FLTS messages from BTS **1 110**, BTS **2 120**, and BTS **3 130**. Each FLTS message may arrive at MS **1 150** at a slightly different time, depending upon the signal propagation delay occurring due to the differing signal paths **152**, **154**, **156** between MS **1 150** and antennas **116**, **126**, and 136, respectively. By time stamping

the arrival times, MS 1 150 may determine the time difference of arrival (TDOA) between the FLTS signals sent by BTS 1 110, BTS 2 120, and BTS 3 130. For convenience, it may be convenient to denote the TDOA between the FLTS sent by a BTS A and the FLTS sent by a BTS B as TDOA (A, B). Using this notation, MS 1 150 may then determine TDOA (1, 2) and TDOA (2,3).

Referring now to FIG. 4, a transmit power timing diagram for the forward link of FIG. 2 is shown, according to one embodiment of the present invention. In the discussion of FIG. 3 above, it was noted that the FLTS signals may be transmitted in a synchronized but periodic manner. The average transmission power of a BTS is limited by Federal Communications Commission (FCC) rules due to concerns about health and other impacts of radiated RF energy. It is therefore not possible to maintain a high RF power transmission of CDMA forward links **240**. Indeed a CDMA mobile telephone system constantly adjusts the transmitted power of both the BTSs and the MSs in order to minimize the average RF power transmission within the system.

In one embodiment of the present invention, for FLTS signals which are periodically transmitted with repetition period P, BTS **1 110**, BTS **2 120**, and BTS **3 130** may temporarily increase the baseline transmitted power X_0 dBW by an amount H dBW during the transmission time required for an FLTS. The value of H will depend upon the transmitters within BTS **1 110**, BTS **2 120**, and BTS **3 130**, and the size of the cells within the CDMA mobile telephone system. The resulting increased transmitted power X_0+H dBW increases the likelihood that MS **1 150** will receive the FLTS signals from each one of BTS **1 110**, BTS **2 120**, and BTS **3 130**. The reception and subsequent determination of DTOA (1, 2) and DTOA (2, 3) are therefore made more likely.

The repetition period P may be chosen so that the time period W required to transmit a FLTS signal is small by comparison. When P is so chosen, the duty cycle W/P is also small, and therefore the average transmitted power is not substantially greater than X_0 dBW. Therefore in one embodiment the ability of MS **1 150** to successfully determine the necessary DTOA values is increased without substantially increasing the average transmitted power.

Referring now to FIG. **5**, the geographical hyperbolas of constant differential time of arrival are illustrated, according to one embodiment of the present invention. In the discussions of FIGS. 3 and 4 above, it was shown how the use of synchronized transmission of FLTS signals allows BS **1 150** to determine the DTOA (1, 2) and DTOA (2, 3). However, knowing the DTOA of several signals does not immediately give the geographic location of MS **1 150**.

The difference between the distance from MS **1 150** to BTS **1 110** and the distance from MS **1 150** to BTS **2 120** is equal to the speed of light times DTOA (1, 2). Therefore, knowing a DTOA, the difference in distance from MS **1 150** to a pair of BTSs may be calculated.

Knowing the geometric locations of antennas **116**, **126**, and **136**, it is possible to derive the location of all points such that the distance from each point to one of the antennas is equal to the distance from that point to another antenna plus a constant amount. By a definition of elementary geometry such a location defines a hyperbola.

For example, consider point **530**. Point **530** is located such that the distance from point **530** to antenna **126** (**534**) is equal to the distance from point **530** to antenna **116** (**532**) plus an amount equal to the speed of light times DTOA (1, 2). The location of all such points defines a hyperbola **510**. In other words, all possible points where a mobile station could potentially determine a DTOA of DTOA (1, 2) is hyperbola **510**. Notice that MS **1 150** is located upon this hyperbola **510**.

By similar reasoning, all possible points where a mobile station could potentially determine a DTOA of DTOA (2, 3) is hyperbola **520**. By determining the geographic location where hyperbola **510** intersects hyperbola **520**, the geographic location of MS **1 150** is determined.

Given the measured geographic locations of the antennas **116**, **126**, and **136**, and the DTOA (1, 2) and DTOA (2, 3), it is well known in the computational art how to calculate the geographic locations of hyperbolas **510** and **520**. Similarly it is well known in the computational art how to find the geographic location of the intersection of hyperbolas **510** and **520**.

To summarize, the geographic locations of the antennas of the BTSs may be determined in advance by surveying or by using a GPS receiver. Knowing these geographic locations and determining the DTOA times of the FLTS, the geographic location of an MS may be calculated.

In one embodiment the calculation of the hyperbolas and their intersection point may be carried out by processors within MS **1 150**. MS **1 150** may then transmit its geographic location to MSC **100** for forwarding to PSAP **108** when the need arises, such as when a E911 call is initiated. In alternate embodiments, the DTOA data may be forwarded from MS **1 150** to BSC **104** or MSC **100**. In these embodiments processors within BSC **104** or MSC **100** may perform the calculation of the hyperbolas and their intersection point.

Referring now to FIG. **6**, a flowchart of the determination of the mobile station's geographic location is shown, according to one embodiment of the present invention. In step **610** the mobile station is initialized within the CDMA mobile telephone system by receiving data from pilot channels **310** and sync channels **320**. Then in step **612** the mobile station receives the first in a series of FLTS signals from one of at least three BTSs. The mobile station notes which BTS sent the FLTS and the time of arrival, and time stamps the message. In steps **614** and **616** the mobile station similarly receives, notes the transmitting BTS and time of arrival, and timestamps the messages. Then in step **616** the mobile station determines the values of the DTOA between the three FLTS signals.

In step **620**, the mobile station transmits a message to the base station controller containing the DTOA information determined in step **616**. Then in step **622** the base station controller uses the DTOA information and previously stored geographic location data for the antennas of the base transceiver stations to calculate the location hyperbolas and the point where the hyperbolas intersect. This geographic location is the location of the mobile station at that point in time. The geographic location is then, in step **624**, sent to temporary storage within the mobile switching center for use when required. After the current value of the geographic location of the mobile station is stored, the process repeats and, starting over at step **612**, the mobile station determines subsequent values of DTOA.

In the foregoing specification, the invention has been described with reference to specific embodiments thereof. It will however be evident that various modifications and changes can be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense. Therefore, the scope of the invention should be limited only by the appended claims.

What is claimed is:

1. A method for determining the geographic location of a mobile station in a mobile telephone system, comprising:

receiving a plurality of forward link triangulation signals at said mobile station, wherein said plurality of forward link triangulation signals are received with increased transmitted power occurs during a duty cycle;

timestamping said forward link triangulation signals within said mobile station;

calculating a first hyperbola and a second hyperbola from said timestamped forward link triangulation signals; and

calculating the intersection of said first hyperbola and said second hyperbola.

2. The method of claim 1, wherein said receiving is continuously or periodically.

3. The method of claim 1, wherein said increased transmitted power includes adjusting said duty cycle such that average transmitted power is limited to a predetermined level.

4. The method of claim 1, wherein said timestamping includes calculating differential time of arrival values.

5. The method of claim 4, wherein said calculating said first hyperbola and said second hyperbola utilizes said differential time of arrival values.

6. The method of claim 1, further comprising broadcasting said plurality of forward link triangulation signals from a plurality of base transceiver stations.

7. The method of claim 6, wherein said increased transmitted power is provided at the plurality of base transceiver stations.

8. The method of claim 6, wherein said broadcasting is synchronized by a time standard.

9. The method of claim 8, wherein said time standard is set by a global positioning system.

10. A system for determining the geographic location of a mobile station in a mobile telephone system, comprising:

a plurality of forward link triangulation signals received at said mobile station, wherein said forward link triangulation signals are received with increased transmitted power during a duty cycle;

a receiver configured to couple a plurality of timestamped values to said forward link triangulation signals within said mobile station;

a first processor configured to calculate a first hyperbola and a second hyperbola from said timestamped values coupled to said forward link triangulation signals; and

a second processor configured to calculate an intersection point of said first hyperbola and said second hyperbola.

11. The system of claim 10, wherein said forward link triangulation signals are received continuously or periodically.

12. The system of claim 10, wherein said duty cycle is adjustable such that average transmitted power is limited to a predetermined level.

13. The system of claim 10, wherein said forward link triangulation signals are broadcast from a plurality of base transceiver stations.

14. The system of claim 13, wherein said increased transmitted power is provided at the plurality of base transceiver stations.

15. The system of claim 10, wherein said receiver couples differential time of arrival values to said forward link triangulation signals.

16. The system of claim 15, wherein said first processor utilizes said differential time of arrival values.

17. The system of claim 10, wherein said base transceiver stations are synchronized by a time standard.

18. The system of claim 17, wherein said time standard is set by a global positioning system.

19. A machine-readable medium having stored thereon executable code which causes a machine to perform a method, for determining the geographic location of a mobile station in a mobile telephone system, the method comprising:

receiving a plurality of forward link triangulation signals at said mobile station, wherein said plurality of forward link triangulation signals are received with increased transmitted power occurs during a duty cycle;

timestamping said forward link triangulation signals within said mobile station;

calculating a first hyperbola and a second hyperbola from said timestamped forward link triangulation signals; and

calculating the intersection of said first hyperbola and said second hyperbola.

20. The machine-readable medium of claim 19, wherein the method further comprises adjusting said duty cycle such that average transmitted power is limited to a predetermined level.

21. The machine-readable medium of claim 19, wherein said timestamping includes calculating differential time of arrival values.

22. The machine-readable medium of claim 19, wherein said calculating said first hyperbola and said second hyperbola utilizes said differential time of arrival values.

23. The machine-readable medium of claim 19, wherein said increased transmitted power is provided from a plurality of base transceiver stations.

* * * * *